

**American Clinical Neurophysiology Society Guideline 6: Minimum Technical Standards for EEG
Recording in Suspected Cerebral Death**

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Abstract

This revision to the EEG Guidelines is an update incorporating current electroencephalography technology and practice. The role of the EEG in making the determination of brain death is discussed as are suggested technical criteria for making the diagnosis of electrocerebral inactivity.

Key Words

Electroencephalography equipment, Electroencephalography electrode, Electroencephalography montage, Electroencephalography brain death, Electroencephalography report, Adult, Pediatric, Neonatal

American Clinical Neurophysiology Society

Guideline 6: Minimum Technical Standards for EEG Recording in Suspected Cerebral Death

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This guideline emphasizes the basic principles and other important aspects of recording the electroencephalogram (EEG) for the purposes of determining brain death. It serves to update what has been learned since the first iteration of minimum technical standards for the determination of brain death (Chatrian et al., 1974; Bennett et al., 1976; Chatrian, 1980; NINCDS, 1980; Medical Consultants, 1981; Walker, 1981). Clinical scenarios may vary by policies required by individual states or hospitals, so these guidelines for minimal standards must be taken in the context of individual resource availability. Consequently, this document should be considered as an expression of the optimal means of recording and not as an absolute requirement. In particular, because of the complexities involved in evaluating the pre-term infant, these guidelines do not refer to those patients.

Introduction

Many hospitals have intensive care units and perform EEG studies in the setting of clinically suspected cerebral death to confirm irreversible loss of all brain function (Wijdicks et. al. 2010). For this reason, there is continued need for guidance in performing these important tests.

The first (1970) edition of *Minimum Technical Requirements for EEG Recording in Suspected Cerebral Death* reflected the state of the art and techniques of the late 1960s. Substantially improved EEG technology is now available, and many laboratories have had decades of experience in this area. Equally important, there is now a much larger complement of qualified EEG technologists.

An initial survey in the late 1960s by the American EEG Society's *ad hoc* Committee on EEG Criteria for the Determination of Cerebral Death revealed that, of 2,650 cases of coma with presumably "isoelectric" EEGs, only three cases with recordings satisfying the committee's criteria showed any subsequent recovery of cerebral function. These three patients had suffered from massive overdoses of central nervous system depressants. Many of the reported "isoelectric" records in adults were, on review, either low-voltage records or obtained with techniques inadequate to show low-voltage activity such that they gave the false appearance of being "flat."

Non-physiologic terms such as “electrocerebral silence, isoelectric,” “linear,” and “flat” were replaced in the 1970s with the term “electrocerebral inactivity” (ECI) that appears in the Glossary of the International Federation of Clinical Neurophysiology (IFCN; Chatrian et al., 1974). A recent study found that in 96.5% of patients, the EEG corroborated the clinical diagnosis of brain death, but in 3.5% of patients it did not (Fernandez-Torre et. al., 2013) -- particularly in patients with brainstem injury. In these patients, the EEG demonstrated electrical activity in patients who had a diagnosis of brain death on clinical grounds. A study in children (Nakagawa et. al. 2011) yielded different results: only 89% of patients with brain death had an EEG demonstrating ECI. There was a similar finding in neonates and children with radionuclide brain scans; when a single EEG was performed with a radionuclide brain scan, up to 17% of children without apparent flow on the scan still had cerebral activity on the EEG (Nakagawa et. a., 2011).

Definition

Electrocerebral inactivity is defined as the absence of non-artifactual electrical activity over 2 uV (peak to peak) when recording from scalp electrode pairs 10 or more cm apart when the recording is performed in compliance with the standards outlined below.

The guidelines for EEG recordings in cases of suspected cerebral death have eleven components, each set forth with explanatory comments. The basic principles of EEG recording still apply, and, unless modifications are noted below, Guideline 1 recommendations should be followed.

1. A complete complement of scalp electrodes should be utilized.

Electrodes must be placed over all major brain areas to be certain that absence of EEG activity is not just a regional phenomenon. The use of single-channel or dual-channel recording devices such as those used for EEG monitoring of anesthetic levels is therefore unacceptable for the purpose of determining ECI. Especially because the EEGs of patients with suspected ECI may demonstrate abnormalities other than ECI, it is essential to use complete, rather than restricted, electrode coverage, as defined in Guideline 1: *Minimum Technical Requirements for Performing Clinical Electroencephalography*, Section 2.3. This should include midline placements (Fz, Cz, Pz) because these electrodes are useful for the detection of residual low-voltage physiologic activity and are relatively free from artifact. At times, recording with a full set of conventional 10-20 (or 10-10) scalp locations may not be feasible, for example because of head trauma or recent surgery. In this case, electrode positions may be moved as necessary, as long as careful documentation is made and the minimal inter-electrode distances described below are attained. In this case, one option is to displace the same electrodes on the contralateral side by an equivalent distance to allow better comparisons between the two sides. The initial study should not use less than the routine coverage standard for the particular clinical laboratory.

The location of all electrodes placed should be well documented.

All recording devices require an isolated ground and a reference electrode to be connected to the patient. The device manual should be consulted prior to recording.

2. Inter-electrode impedances should be under 10,000 Ohms but over 100 Ohms.

2.1 Unmatched electrode impedances may distort the EEG. When one electrode has relatively high impedance compared to the second electrode of the pair, the amplifier becomes unbalanced and is prone to amplify extraneous signals unduly. This may result in 60-Hz interference or other artifacts.

Situations characterized by low-voltage electrocerebral activity demand especially scrupulous electrode application. In addition, electrodes with high impedance even if matched may be associated with increased noise that could obscure a low amplitude signal.

2.2 There is a marked drop off of potentials with impedances below 100 Ohms and, of course, no potential at 0 Ohms. This could be one possible reason for a false ECI record. A test of inter-electrode impedances, to assure that they are of adequate magnitude, should be performed during the recording. It is essential that excess electrode paste does not spread from one electrode to another, creating a shunt or short circuit, which would also attenuate the signal.

Stable, low-impedance electrodes are absolutely essential for all bedside (i.e., away from the laboratory) studies.

2.3 The use of needle electrodes and “electrode caps” should be avoided.

3. The integrity of the entire recording system should be tested.

If, after recording with one montage at increased amplification, an EEG suggesting ECI is found, the integrity of the system should be tested by touching each electrode of the montage gently with a pencil point or cotton swab to create an artifact potential on the record. This test verifies that the electrode board is connected to the recording device. Records made with the electrode board inadvertently not connected can sometimes resemble low-amplitude EEG activity. The test also proves that the montage settings match the electrode placements.

4. Montages for ECI interpretation should include electrode pairs at least 10 centimeters apart.

In the International 10-20 System, the average adult interelectrode distances are between 6 and 6.5 cm. A recording taken with average interelectrode distances at ordinary sensitivity might suggest ECI, but if it were recorded using longer interelectrode distances, cerebral potentials might be seen in the tracing. Hence, with longitudinal or transverse bipolar montages, several double distance electrode linkages are recommended (e.g., Fp1-C3, F3-P3, C3-O1, etc.). The use of the 10-10 System is also acceptable, using electrodes from similar locations on the scalp.

Ear reference recording is almost invariably too contaminated by ECG to be useful, but a montage including a Cz reference may be satisfactory as long as an interelectrode distance of 10 cm or more is maintained. In one study (Bennett et al., 1976), the best montage included : Fp2-C4, C4-O2, Fp1-C3, C3-O1, T4-Cz (T8-Cz in the 10-10 system), Cz-T3 (Cz-T7 in the 10-10 system), with one-channel ECG and one-channel non-cephalic recording (e.g. on the hand). Occipital leads, however, are more difficult to attach in immobilized patients and are particularly susceptible to movement artifact induced by artificial respirators. A montage that includes F7-T5 (F7-P7 in the 10/10 system), F8-T6 (F8-P8 in the 10-10 system), F3-P3, F4-P4, and Fz-Pz may therefore yield a better record.

None of the foregoing should imply that the usual preselected laboratory montages could not be used in addition.

5. Sensitivity must be increased to a maximum of 2 uV/mm for at least 30 minutes of the recording.

5.1 This is undoubtedly the most important and the most often overlooked specification. At a sensitivity of 7 uV/mm, a signal of 2 uV cannot be seen because it would be less than 0.3 mm in magnitude; on most computer monitors, a single pixel is about 0.25 mm. Recording at a sensitivity of 1.5 or 1 uV/mm provides an additional 50-100% increase in sensitivity and will allow a more confident assessment of the presence, or the absence, of a 2-uV signal. It is important to include appropriate calibrations for the specific recording device utilized.

5.2 Adequate and appropriate calibration procedures are essential. It is good practice to calibrate with a signal near the size or value of the EEG signal that has been recorded. Thus, for electrocerebral inactivity, a calibration signal of 2 or 5 uV is appropriate. A 50-uV calibration signal at a sensitivity of 2 or 1 uV/mm is useless because the monitor traces may overlap. The inherent noise level of the recording device should also be measured as in section 7.5

5.3 It is important to understand the calibration function on the recording device being used and particularly whether it tests the amplifiers or only the display. Nevertheless, adequate calibration does not exclude the possibility of shunting or an open circuit at the electrodes, electrode board (jackbox), cable, or input of the recording device.

5.3 Self-limited periods of ECI of up to 20 minutes may occur in low-voltage records (Jorgensen, 1974), so each recording should be at least 30 minutes long to be certain that intermittent low-voltage cerebral activity is not missed.

6. Filter settings should be appropriate.

In order to avoid attenuation of low-voltage fast or slow activity, high-frequency (low pass) filters should not be set below 30 Hz, and low-frequency (high pass) filters should not be set above 1Hz.

Short time constants (high values of the low filter) attenuate slow potentials. In the situation approaching ECI, there may be potentials in the theta and delta ranges, so every effort should be made to avoid attenuation of this low frequency activity. Nevertheless, it has been demonstrated that a low-frequency setting of 1 Hz is adequate for the determination of ECI (Jorgensen, 1974; Bennett et al., 1976). The 60-Hz notch filter can be used with care, and only after appropriate troubleshooting is performed. If the 60 Hz filter is used, segments of EEG should also be recorded without this filter for comparison.

7. Additional monitoring techniques should be employed when necessary to clarify the record.

The EEG record is a composite of true brain waves, other physiologic signals, and artifacts (either internal or external to the recording device, and of mechanical, electromagnetic, and/or electrostatic origin). When the sensitivity is increased, such artifacts are accentuated and therefore must be identified in order to accurately assess whether true EEG activity is present. It should be emphasized that the best insurance against many artifacts is a stable, low-impedance electrode system. A wide range of artifacts is present in the patients who sustain severe brain insults requiring special care (Tatum et al., 2011). These are illustrated in the *Atlas of Electroencephalography in Coma and Cerebral Death* (Bennett et al., 1976) in *Current Practice of Clinical Electroencephalography* (Chatrian et al., 2003.) and the *Atlas of EEG in Critical Care* (Hirsch et. al. 2010).

7.1 Because one rarely sees an ECI record without varying amounts of electrocardiogram (ECG) artifact, an ECG monitor is essential.

7.2 If respiration artifact cannot be eliminated, the artifact must be documented by specific technologist notation on the record or be monitored by a transducer. Disconnecting the respirator (briefly) will allow definitive identification of the artifact, if clinically appropriate. Review of accompanying video can also be of assistance.

7.3 Frequently, an additional monitor is needed for other artifacts emanating from the patient or the local environment. The most convenient for this purpose is a pair of electrodes on the dorsum of the hand separated by about 6-7 cm. The technologist should be aware of frequent sources of electrical artifact including: electric beds, IV drips, blood warmers, or other electrical devices. The technologist should place additional monitors when they help to clarify the source of artifact. For example, intermittent movements noted in a limb should prompt placement of a movement monitor to help differentiate movement-induced artifact from electrocerebral activity.

7.4 It is clear that some EMG contamination can persist in patients with ECI recordings. If EMG potentials are of such amplitude as to obscure the tracing, it may be necessary to reduce or eliminate them by use of a short term neuromuscular blocking agent. Because this may interfere with the neurologic examination and cause other problems, neuromuscular blockade should be performed under the direction of an experienced physician familiar with the use of medications in critically ill patients.

7.5 Machine noise, thermal noise, and electrical interference entering the recording system from the jack box to the amplifiers may be checked conveniently by placing a 10,000-Ohm resistor between input terminal 1 (G1) and input terminal 2 (G2) of one channel, as long as either G1 or G2 is shorted to the reference electrode.

7.6 Even with good technique, however, an EEG recorded at the increased sensitivities required above can occasionally present diagnostic challenges to the interpreting electroencephalographer. An attempt must be made to determine what portion of the record results from noncerebral physiologic signals, or nonphysiologic artifacts, including the ongoing noise level of the complete system in that particular ICU, as indicated, for example, by a recording from the hand. An estimate must then be made of whether or not the remaining activity exceeds 2 uV in amplitude. When this cannot be done with confidence, the EEG report must indicate the uncertainty, and the record cannot be classified as demonstrating ECI (see Section 10).

7.7 Continuous video recording is strongly encouraged in order to help identify any artifacts in the recording. Furthermore, recognizing the source of the artifact in order to “troubleshoot” and eliminate or camouflage it from the record requires a coordinated team, including trained technologists, nurses, personnel experienced in informatics, and neurophysiologists, to ensure optimal interpretation.

8. There should be no EEG reactivity to intense somatosensory, auditory, or visual stimuli.

Lack of reactivity in critically ill patients is associated with an increase in mortality (Gilmore EJ et al., 2015). In this collaborative study, there was no instance of stimulus-related activity in EEG recordings of patients with ECI (Bennett et al., 1976; NINCDS, 1980; Walker, 1981). Any apparent EEG activity resulting from the above stimuli or any others (airway suctioning and other nursing procedures can be potent stimuli) must be carefully distinguished from noncerebral physiologic signals and from nonphysiologic artifacts. For example, an electroretinogram can persist in response to photic stimulation when there is ECI. Stimulation may also be of help in documenting the degree of reactivity in records not demonstrating ECI.

9. Recordings should be performed only by a qualified technologist.

Great skill is essential in recording cases of suspected ECI. Frequently, recordings are made under difficult circumstances and include many possible sources of artifact. Elimination of most artifact, and identification of all others, can be accomplished only by a qualified technologist.

Qualifications for a competent EEG technologist for ECI recordings include the requirement of supervised instruction in the techniques of recording in ICU settings, as well as prior successful performance of ECI recordings under direct supervision. Additionally, Registry in EEG Technology (R. EEG T.) is encouraged for technologists performing such studies. The technologist should work under the direction of a qualified electroencephalographer. The American Academy of Neurology and the ACNS, in conjunction with the American Board of Clinical Neurophysiology, have established guidelines for physician standards of reporting and interpretation.

10. A repeat EEG should be performed when ECI is in doubt.

In the Collaborative Study of Cerebral Death (Bennett et al., 1976; NINCDS, 1980; Walker, 1981), there were no patients who survived for more than a short period after an EEG showed ECI -- provided that overdose of depressant drugs was excluded. This finding confirmed the results of the earlier survey summarized in the Introduction. It is evident, therefore, that a single EEG showing ECI is a highly reliable procedure for the determination of cortical death. While that is likely true for term neonates and children, an EEG can not substitute for a neurologic examination in a brain death evaluation (For other guidelines to assist physicians in the determination of brain death, see the References.)

In the event that technical or other difficulties lead to an inconclusive EEG evaluation of ECI, the entire procedure should be repeated after an interval to resolve any uncertainty. This may be as short as 6 hours in adult patients, but in neonates and children the interval should be at least 24 hours. Consideration could be given to other confirmatory tests if, in the opinion of the treating physicians, technical limitations are unlikely to be overcome in subsequent recordings.

11. Recording of physiological variables and medications.

EEG is subject to many errors in interpretation, some involving non-physiologic variables (Gaspard & Hirsch, 2013). Nevertheless, physiologic variables and the effects of medication are equally important because low core temperature and iatrogenic hypothermia can cause reversible cerebral inactivity (Stecker et. al. 2001). In addition, the blood pressure and oxygen saturation should be recorded, as both hypotension and hypoxemia can cause loss of cerebral activity. Finally, it is important to record all medications the patient is taking, as well as the last time that the patient received any sedating medications such as barbiturates, benzodiazepines, propofol, or narcotics. If the patient has had a toxicology screen, the technologist should also document the results.

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